
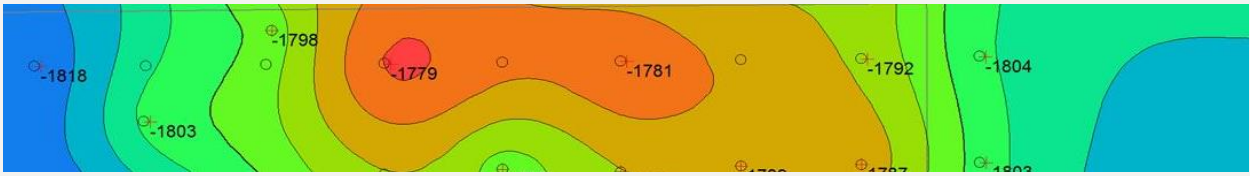

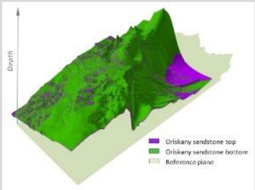


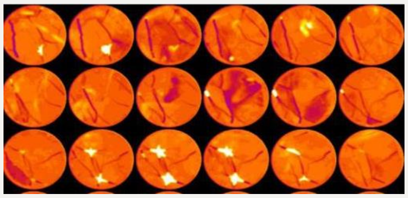


Petronius Offshore Oil Field Case Study

June 16, 2020
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Disclaimer

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ACRONYMS AND ABBREVIATIONS

ϕ	Reservoir porosity
A	Accessible Oil Area (acres)
API	American Petroleum Institute
ARI	Advanced Resources International
atm	Atmosphere
bbl	Barrel
bbl/d	Barrels per day
Bcf	Billion cubic feet
Boi	Initial oil formation volume factor
CO_2	Carbon dioxide
DOE	Department of Energy
DP	Dykstra-Parsons
EOR	Enhanced oil recovery
F	Net payzone thickness (feet)
ft	Foot, feet
ft^3	Cubic feet
GOM	Gulf of Mexico
K	Kelvin
km	Kilometer
Mbbl	Thousand barrels
Mcf/bbl	Thousand cubic feet per barrel
mD	Millidarcy
MESA	Mission Execution and Strategic Analysis
MMbbl(s)	Million barrels
MMcf	Million cubic feet
MMcfd	Million cubic feet per day
MMSCF	Million standard cubic feet
MW	Molecular weight
NETL	National Energy Technology Laboratory
OCS	Outer continental shelf
OOIP	Original oil in place
Pc	Critical pressure
Ave Pres POVO SCTR	Average pressure for pore volume per sector
psi	Pounds per square inch
psia	Pounds per square inch absolute
rb	Reservoir barrel
SC	Standard Conditions
scf/bbl	Standard cubic feet per barrel
SI	Shut in
Sim	Simulated
Soi	Initial oil saturation
Sor	Residual oil saturation
Stb	Stock tank barrel
Swi	Initial water saturation
Tc	Critical temperature
U.S.	United States
VK 786	Petronius deepwater oilfield
°F	Degrees Fahrenheit

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1 Introduction

Offshore Gulf of Mexico (GOM) outer continental shelf (OCS) oil fields offer significant potential for storage of captured carbon dioxide (CO_2) emissions and incremental oil production using CO_2 enhanced oil recovery (EOR). Understanding the scope and potential of these resources requires in-depth analysis of offshore oil field geologic settings and projects costs. The National Energy Technology Laboratory (NETL) has developed a robust set of onshore CO_2 EOR modeling tools (e.g., the Fossil Energy/NETL CO_2 Prophet Model [CO_2 Prophet Model]), [1] [2] which may be adaptable for modeling offshore CO_2 EOR resources and projects costs. However, developing a set of offshore CO_2 EOR modeling tools requires significant understanding of offshore reservoir characteristics, oil field infrastructure, and project economics. Therefore, it is important to develop a knowledge base of GOM OCS offshore oil reservoir geology and understand the challenges of offshore oil field development and operation in greater detail. Given that the overall offshore CO_2 EOR concept is in its infancy, there is very little field data available to inform model development.

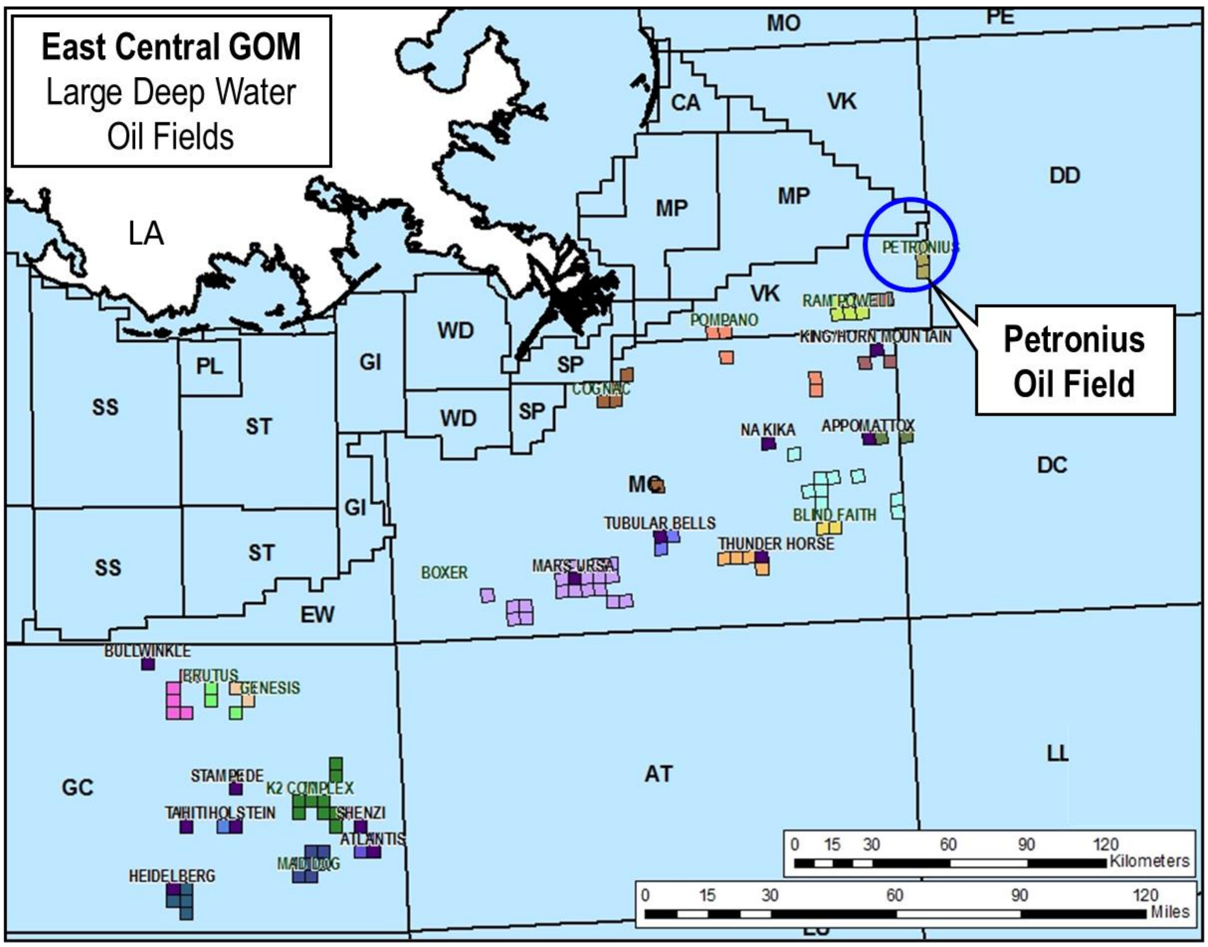
For this study, a small subset of GOM OCS offshore oil fields were investigated and then case studies on the Cognac oil field [3] and Petronius oil field (discussed in this report) were conducted to generate a body of knowledge on the potential offshore CO_2 EOR concept, so that models with the ability to reliably replicate potential offshore CO_2 EOR operations can later be developed. The primary purpose of this study is to assess to what extent the CO_2 Prophet Model is able to reasonably represent the performance of an offshore CO_2 flood, including appropriately capturing the geologic complexity and irregular well spacings typical of offshore oil fields. To perform the assessment of the capabilities of the CO_2 Prophet Model, the following seven tasks were completed:

1. Built a representative geologic model for the Petronius oil field J-2 Sand, including capturing its structural setting and associated aquifer
2. Assembled the key reservoir properties of the J-2 Sand, including its volumetric data, fluid flow capabilities (including relative permeability curves), and oil composition to construct a reservoir model
3. Established the locations of the existing oil/gas production wells in the J-2 Sand
4. Used Computer Modelling Group Ltd.'s GEM compositional simulator ("GEM") to provide a "first-order" history match of fluid production from the J-2 Sand and to calibrate the J-2 Sand's geologic and reservoir description with its oil, gas, and water production history
5. Appraised the performance of a post-primary CO_2 EOR project in the J-2 Sand using GEM with a calibrated geologic/reservoir description
6. Appraised the performance of a post-primary CO_2 EOR project in the J-2 Sand using the CO_2 Prophet Model (a variant of the NETL CO_2 Prophet Model with similar functionality and performance analysis) in parallel with GEM
7. Compared the modeling results of a post-primary CO_2 EOR project in the Petronius oil field J-2 Sand from GEM and the CO_2 Prophet Model to determine whether the CO_2 Prophet Model could reasonably represent the performance of the CO_2 flood compared to the more sophisticated GEM

2 PETRONIUS OIL FIELD

The Petronius deepwater oil field (VK 786) is located in 1,790 feet (ft) of water in the East Central GOM (Exhibit 2-1). [4] The Petronius oil field, with 162 million barrels (MMbbl) of original oil reserves and 200 billion cubic feet (Bcf) of original gas reserves, has produced over 96 percent of its original oil reserves and about 95 percent of its original gas reserves as of the end of 2016. Oil production, which peaked at 70,000 barrels per day (bbl/d) in 2003, declined to 6,000 bbl/d in 2017, placing the Petronius oil field on a list of oil fields facing near-term abandonment and making it a top candidate for EOR using injection of CO_2.

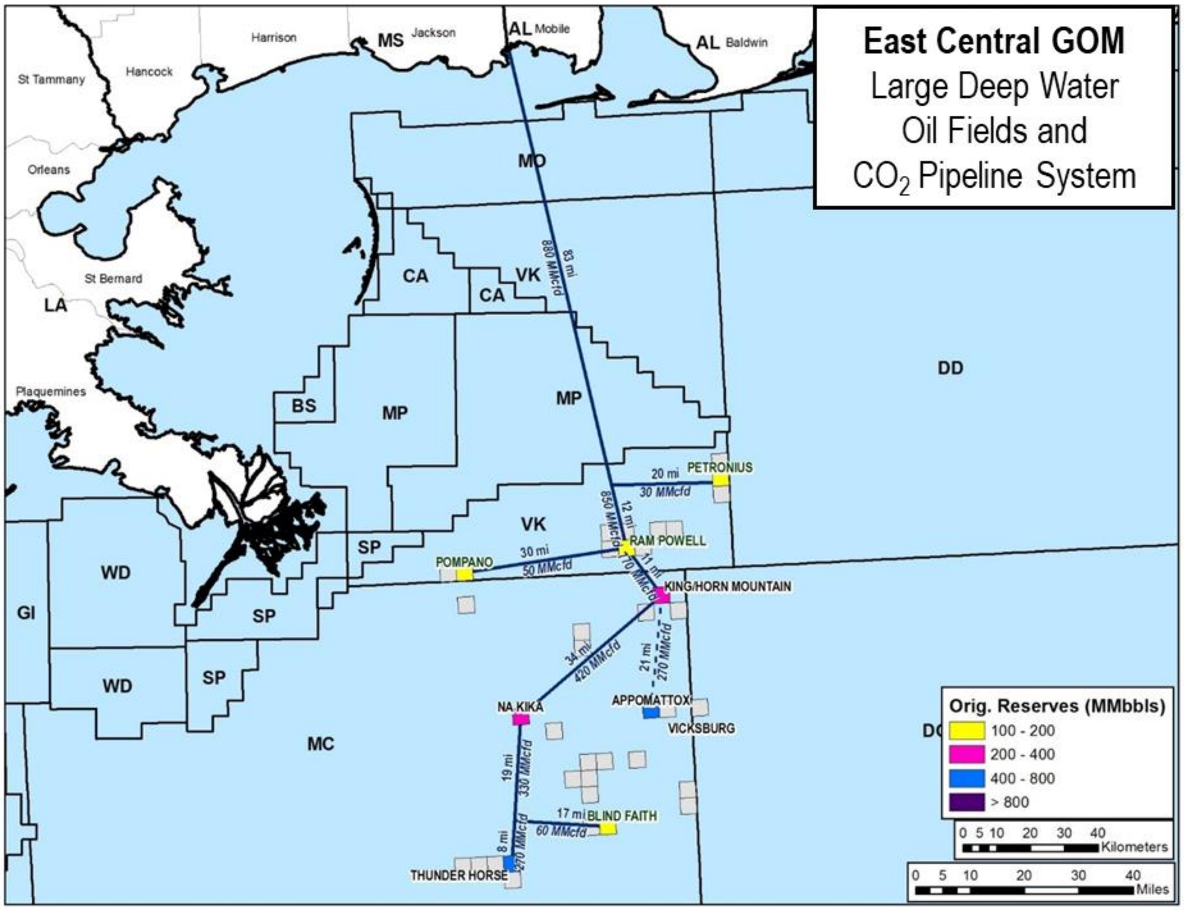
Exhibit 2-1. Location of Petronius oil field, East Central GOM



At the time of its installation in 2000, Petronius's compliant tower structure, designed to absorb nearly 100 mile-per-hour winds and 74-ft waves, was the world's largest offshore oil and gas platform. Since then, Petronius's claim as the largest offshore platform has been surpassed by the Perdido and Mars B/Olympus platforms in the GOM. A notable feature of Petronius is its early installation of a waterflood due to the presence of a relatively weak underlying aquifer.

Exhibit 2-2 illustrates how a regional offshore CO_2 pipeline system could connect the Petronius oil field to CO_2 supplies from onshore Alabama, enabling a CO_2 EOR project to proceed. [4]

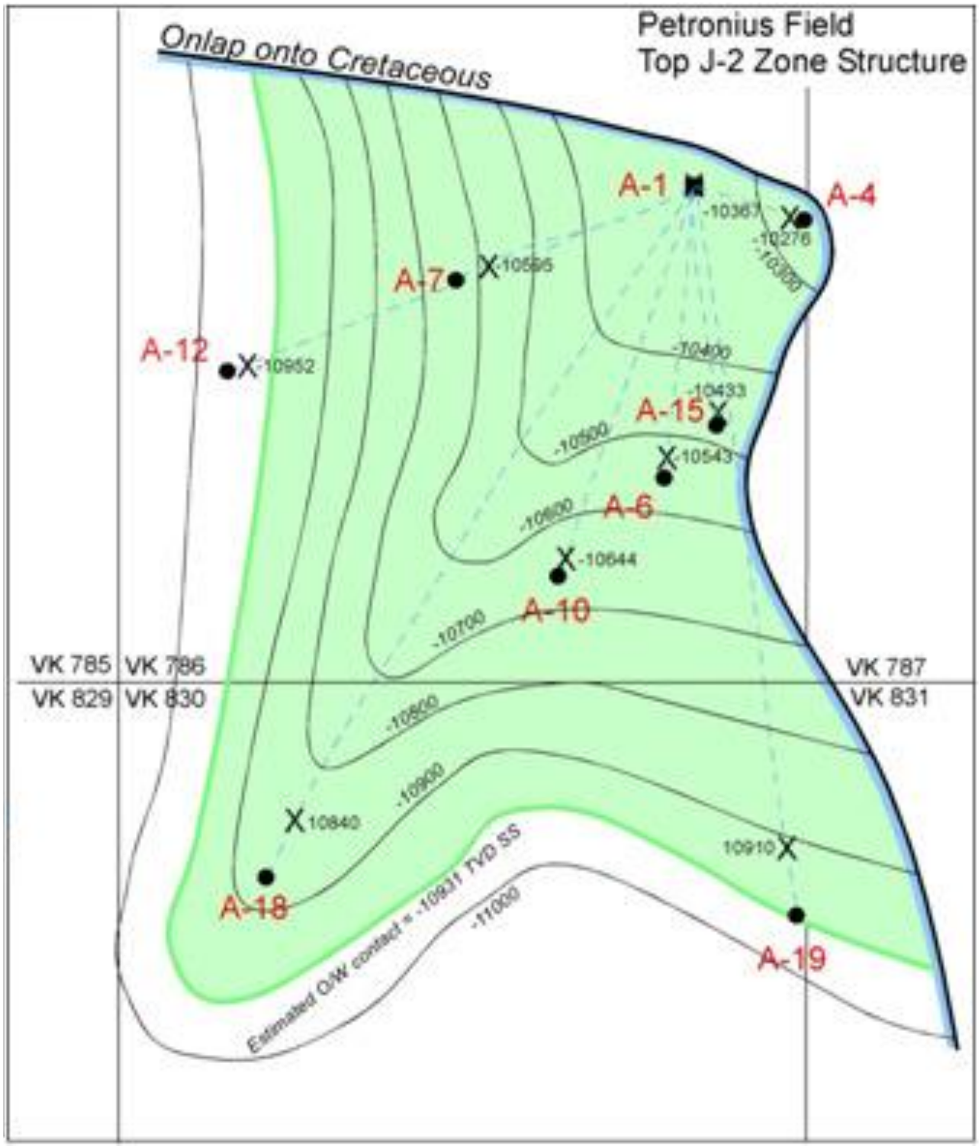
Exhibit 2-2. Potential CO_2 pipeline system for Petronius oil field, East Central GOM



2.1 STRUCTURAL SETTING

The Petronius oil field J-2 Sand reservoir was deposited as a Middle Miocene sheet sand, providing a structurally and stratigraphically relatively simple geologic setting. There is little faulting within the Petronius oil field; the J-2 Sand reservoir is judged to be relatively continuous (Exhibit 2-3).

Exhibit 2-3. Petronius oil field J-2 Sand structure map



Used with permission from the Society of Petroleum of Engineers. [5]

2.2 Petronius Oil Resources

The Petronius oil field contains two major sands, the Miocene-age Upper (J-1) Sand and Middle (J-2) Sand, as well as a series of smaller oil sands (Exhibit 2-4). The J-2 Sand, the second largest sand in the Petronius oil field, with 106 MMbbl of original oil in place (OOIP) and an expected recovery efficiency of about 50 percent (after waterflooding), is a potential candidate for CO_2 EOR. The somewhat larger, 125 MMbbl J-1 Sand has a higher expected oil recovery of nearly 60 percent, leaving a lower residual oil saturation and thus lower incremental oil recovery potential than the J-2 Sand.

Three additional sands exist in the Petronius oil field: J-3, J-4, and J-5. Each of these sands has an OOIP of less than 50 MMbbl and is too small for a standalone EOR project; however, joint development with the larger J-1 and J-2 sands could enable one or more of these sands to become an EOR candidate. [4]

Exhibit 2-4. Petronius oil resources, cumulative production, and remaining reserves

Sands	Oil Area (Acres)	OOIP (MMbbl)	Cumulative Oil Production[A] (MMbbl)	Remaining Oil Reserves[A] (MMbbl)
Major Sands				
J-1	3,438	124.8	69.6	4.0
J-2	5,288	105.0	52.0	1.3
Minor Sands				
J-3	1,352	24.5	6.1	1.0
J-4	1,398	39.2	17.8	0.9
J-5	389	18.2	7.8	1.5
Others	-	0.7	0.2	-
Total	11,865	312.4	153.5	8.7

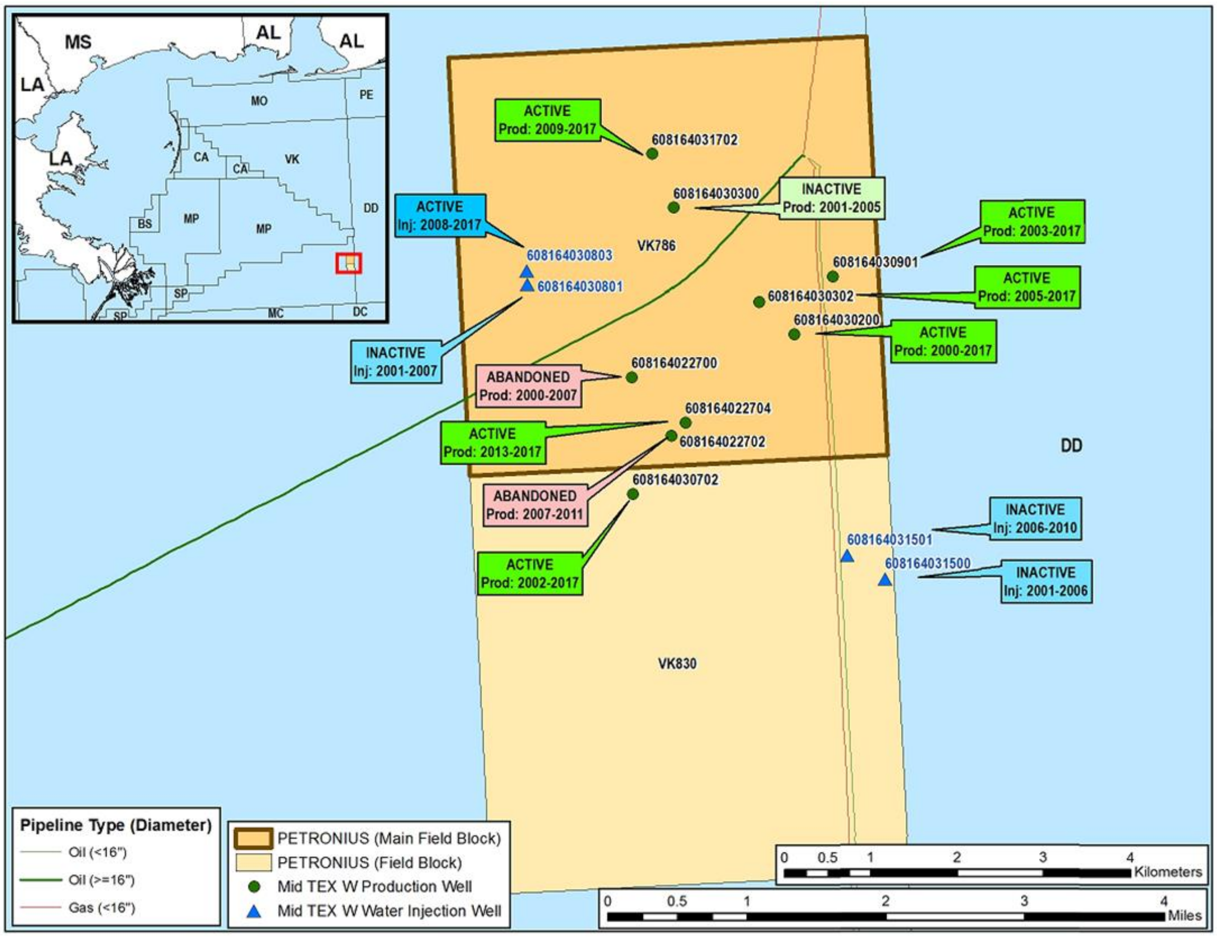
[A]As of end of 2016

Source: Bureau of Ocean Energy Management (BOEM) data, 2018

3 Petronius Oil Field Block VK 786 J-2 Sand

The reservoir modeling addresses the J-2 Sand in Block VK 786 of the Petronius oil field. The Block VK 786 J-2 Sand has been developed with nine production and four water injection wells. As of the end of 2017, six of the production wells and one of the water injection wells are still active (Exhibit 3-1). [6]

Exhibit 3-1. Oil production and water injection wells, Petronius oil field Block VK 786 J-2 Sand



Source: Used with permission from Advanced Resources International [6]

The key volumetric and reservoir properties for the Petronius oil field Block VK 786 J-2 Sand used for reservoir simulation are provided in Exhibit 3-2.

Exhibit 3-2. Reservoir properties, Petronius oil field Block VK 786 J-2 Sand

Property	Value
Accessible Oil Area (acres)	5,700
Porosity (%)	28
Permeability Horizontal (mD)	398
Permeability Vertical (mD)	40
Permeability Anisotropy	5 to 1
Net Pay (ft)	16
Oil Gravity (°API)	31
Swi	0.23
Boi (rb/stb)	1.44
OOIP (MMbbl)	106
Gas/Oil Ratio (scf/bbl)	982
Initial Pressure (at 8,297 ft) (psia)	5,800
Initial Reservoir Temperature (°F)	182

Based on the reservoir properties in Exhibit 3-2, the OOIP for the Petronius oil field Block VK 786 J-2 Sand is 106 MMbbl, as calculated below:

$$\text{OOIP} = (A * F) * 7758\,(\emptyset * Soi/Boi)$$

$$= (5{,}700 * 16) * 7{,}758 \text{ B/AF } (0.28 * 0.77/1.44)$$

$$= (19{,}200 \text{ AF}) * (1{,}162 \text{ B/AF})$$

$$= 106 \text{ MMbbl}$$

In the OOIP equation above, A is the accessible oil area, F is the average payzone net thickness, Soi is the initial oil saturation, and ϕ is reservoir porosity. Oil production from the Petronius oil field Block VK 786 J-2 Sand has declined rapidly in recent years. After a peak of 22,400 bbl/d in 2003, oil production from the J-2 Sand declined to 1,900 bbl/d in 2017. Exhibit 3-3 illustrates the oil production history for the nine production wells in the Petronius oil field J-2 Sand. [7] As of the end of 2017, the J-2 Sand had produced 52 MMbbl of oil, with 1.3 MMbbl of remaining reserves available from secondary (waterflooding) recovery. As such, overall oil recovery is expected to exceed 50 percent of OOIP ([106 MMbbl-52 MMbbl]/ 106 MMbbl = 50.9 percent).

Exhibit 3-3. Petronius oil field Block VK 786 J-2 Sand oil production 2000–2017

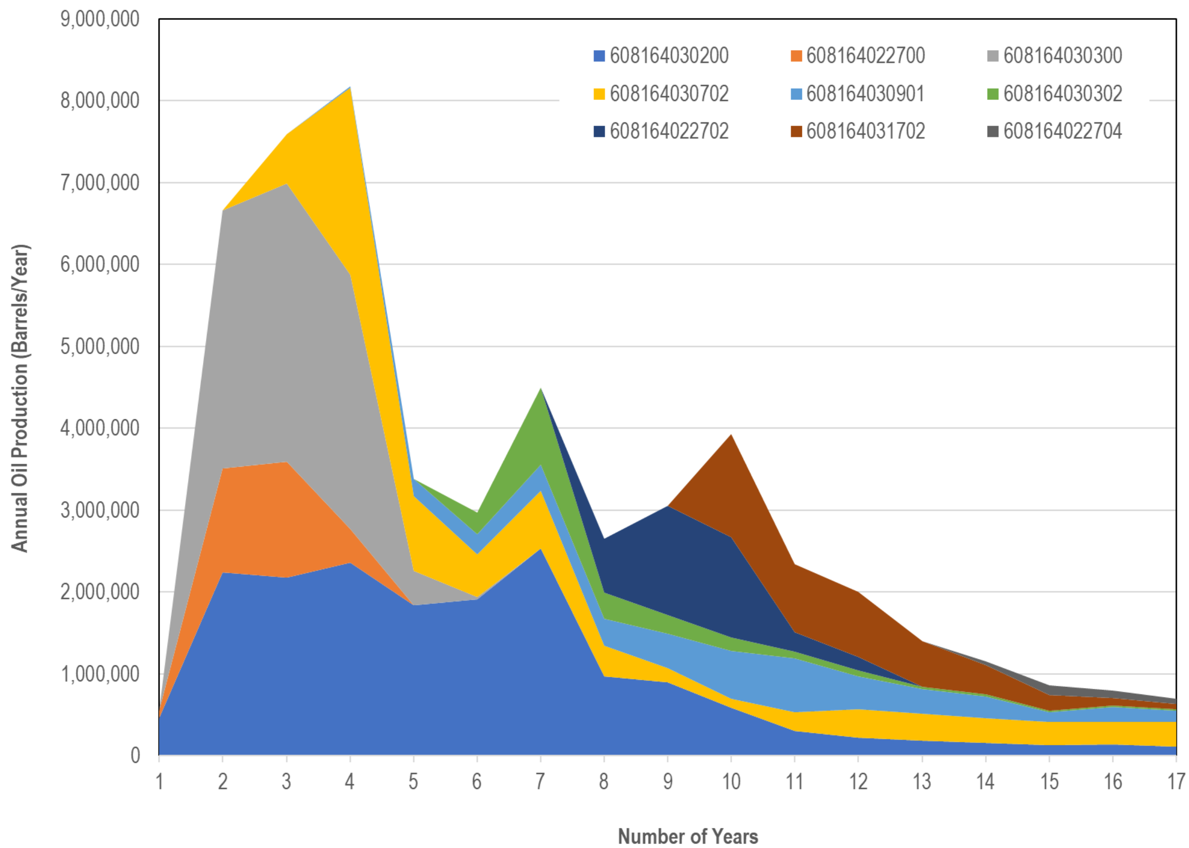


Exhibit 3-4 provides tabular data on the annual oil production history for the nine oil production wells of the Petronius oil field Block VK 786 J-2 Sand. [7] Exhibit 3-5 provides a summary of water injection data from 2000 to 2017 for the waterflood in the Petronius oil field Block VK 786 J-2 Sand. [7] A cumulative of 118 MMbbl of water has been injected over 18 years.

Exhibit 3-4. Petronius oil field Block VK 786 J-2 Sand oil production 2000–2017 (bbl)

Year	Well API ID (last five digits)									Total (bbl)
	30901	22700	30300	30702	30901	30302	22702	31702	22704	
2000	463,966	91,496	-	-	-	-	-	-	-	**555,462**
2001	2,238,076	1,275,758	3,145,503	-	-	-	-	-	-	**6,659,337**
2002	2,181,132	1,408,749	3,396,552	605,209	-	-	-	-	-	**7,591,642**
2003	2,362,544	411,435	3,098,410	2,287,593	18,167	-	-	-	-	**8,178,149**
2004	1,838,280	391	418,917	920,037	209,826	-	-	-	-	**3,387,451**
2005	1,910,395	-	27,929	520,556	250,523	258,627	-	-	-	**2,968,030**
2006	2,532,016	-	-	704,357	322,074	935,412	-	-	-	**4,493,859**
2007	968,174	-	-	382,673	326,639	314,102	660,163	-	-	**2,651,751**
2008	897,819	-	-	171,320	421,910	226,733	1,334,035	-	-	**3,051,817**
2009	591,792	-	-	105,678	586,058	160,309	1,227,527	1,262,416	-	**3,933,780**
2010	304,182	-	-	233,187	649,472	88,699	235,396	834,927	-	**2,345,863**
2011	226,460	-	-	341,511	400,223	75,333	162,352	798,410	-	**2,004,289**
2012	184,391	-	-	334,495	298,997	30,456	-	556,363	-	**1,404,702**
2013	157,279	-	-	301,401	265,807	31,895	-	351,298	49,516	**1,157,196**
2014	134,867	-	-	278,273	122,713	16,525	-	189,245	116,821	**858,444**
2015	145,487	-	-	272,831	179,730	14,724	-	92,252	93,068	**798,092**
2016	110,599	-	-	302,725	136,954	15,666	-	71,838	57,840	**695,622**
2017	36,927*	-	-	164,956	53,014	2,169	-	20,603	20,557	**298,226**
Total	**17,284,386**	**3,187,829**	**10,087,311**	**7,926,802**	**4,242,107**	**2,170,650**	**3,619,473**	**4,177,352**	**337,802**	**53,033,712**

*As of August 2017

Exhibit 3-5. Petronius oil field Block VK 786 J-2 Sand water injection 2000–2017

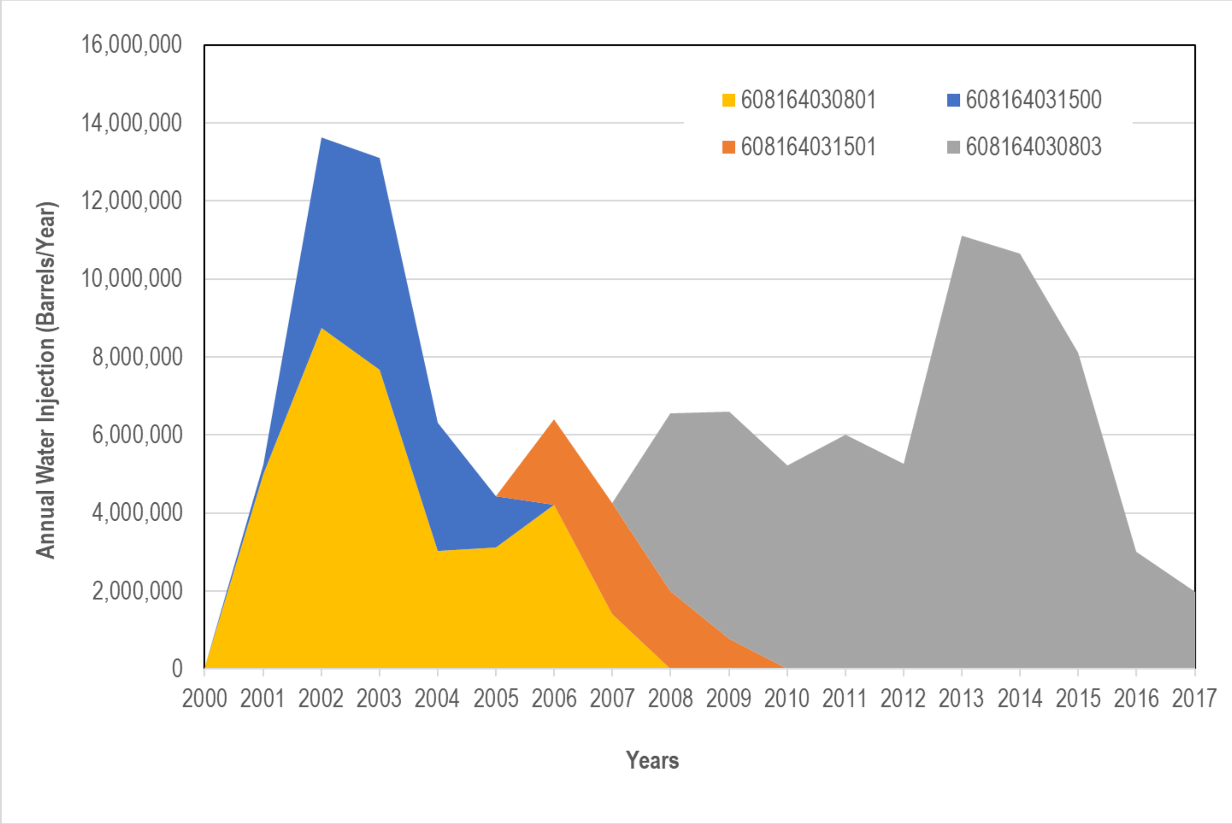


Exhibit 3-6 and Exhibit 3-7 provide hydrocarbon composition and binary interaction coefficients used, respectively, for the 31° American Petroleum Institute (API) gravity in the Petronius oil field Block VK 786 J-2 Sand with a gas/oil ratio of 982 standard cubic feet per barrel (scf/bbl). The oil composition used for the GEM model was based on data from Li et al. (2017) for a Wolfcamp reservoir oil with similar API gravity and reservoir characteristics. [8]

Exhibit 3-6. Oil composition, Petronius oil field Block VK 786 J-2 Sand

Component	Mole Fraction
CO_2	0.35
N2	1.16
C1	38.32
C2	8.66
C3	8.55
iC4	1.06
C4	4.86
C5-C6	7.66
C7-C12	15.70
C13-C21	7.50
C22+	6.23

Modified from Li, 2017.

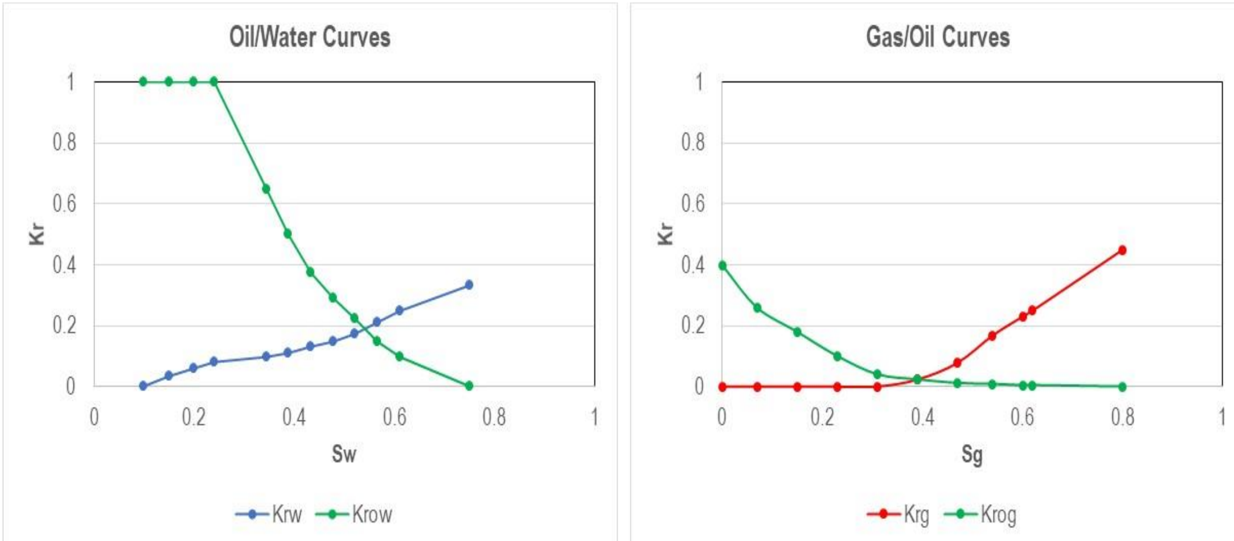
Exhibit 3-7. Binary interaction coefficients used for the Petronius oil field Block VK 786 J-2 Sand

Component	Pc (atm)	Tc (K)	MW	Binary Interaction Coefficients							
				CO_2	N_2	C1	C2	C3	IC4	NC4	C5-6
CO_2	72.8	304.2	44.01	0							
N_2	33.5	126.2	28.01	0	0						
C1	45.4	190.6	16.04	0.105	0.025	0					
C2	48.2	305.4	30.07	0.13	0.01	0.0027	0				
C3	41.9	369.8	44.09	0.125	0.09	0.0085	0.0017	0			
IC4	36	408.1	58.12	0.12	0.095	0.0157	0.0055	0.0011	0		
NC4	37.5	425.2	58.12	0.115	0.095	0.0147	0.0049	0.0009	0.0000	0	
C5-6	31.4	486.4	78.3	0.115	0.1	0.0319	0.0165	0.0077	0.0030	0.0035	0
C7-12	24.7	585.1	120.6	0.115	0.11	0.0470	0.0279	0.0162	0.0089	0.0097	0.0016
C13-21	17.0	740.1	220.7	0.115	0.11	0.1003	0.0728	0.0539	0.0402	0.0417	0.0218
C22-80	12.9	1024	443.5	0.115	0.11	0.1266	0.0964	0.0750	0.0590	0.0608	0.0365

Modified from Li, 2017.

Exhibit 3-8 provides the relative permeability curves for oil/water and gas/oil used for history matching the Petronius oil field Block VK 786 J-2 Sand produced fluids.

Exhibit 3-8. Relative permeability for oil/water and gas/oil, Petronius oil field Block VK 786 J-2 Sand



4 Reservoir Model for the Petronius Oil Field Block VK 786 J-2 Sand

This section describes the reservoir model, which includes key reservoir properties such as volumetric data and oil composition, for the Petronius oil field Block VK 786 J-2 Sand. This section also discusses calibration of the reservoir model.

4.1 Constructing the Reservoir Model

The reservoir model for the Petronius oil field Block VK 786 J-2 Sand contains 79 grid blocks in the X directive and 79 grid blocks Y directive, with each grid block set at 400 x 400 ft. The up-structure portion of the reservoir model area, equal to 5,700 acres, represents the oil-saturated area of the J-2 Sand. The down-structure portion of the reservoir model area represents the underlying aquifer. The thickness of the J-2 Sand of 16 ft was sub-divided into 3 layers, 5.33 ft per layer, to provide higher resolution and to model gravity effects on injected and produced fluids.

Exhibit 4-1 illustrates the structure and depth of the Petronius oil field Block VK 786 J-2 Sand as well as the oil-water contact and location of its nine production and four injection wells. [7] A northeast/southwest 1.8-degree dip was implemented. All wells (nine producers and four water injectors) were placed in the model based on their available borehole locations. The depth of each well was checked for accuracy.

Exhibit 4-1. Petronius oil field Block VK 786 J-2 Sand structure and depth

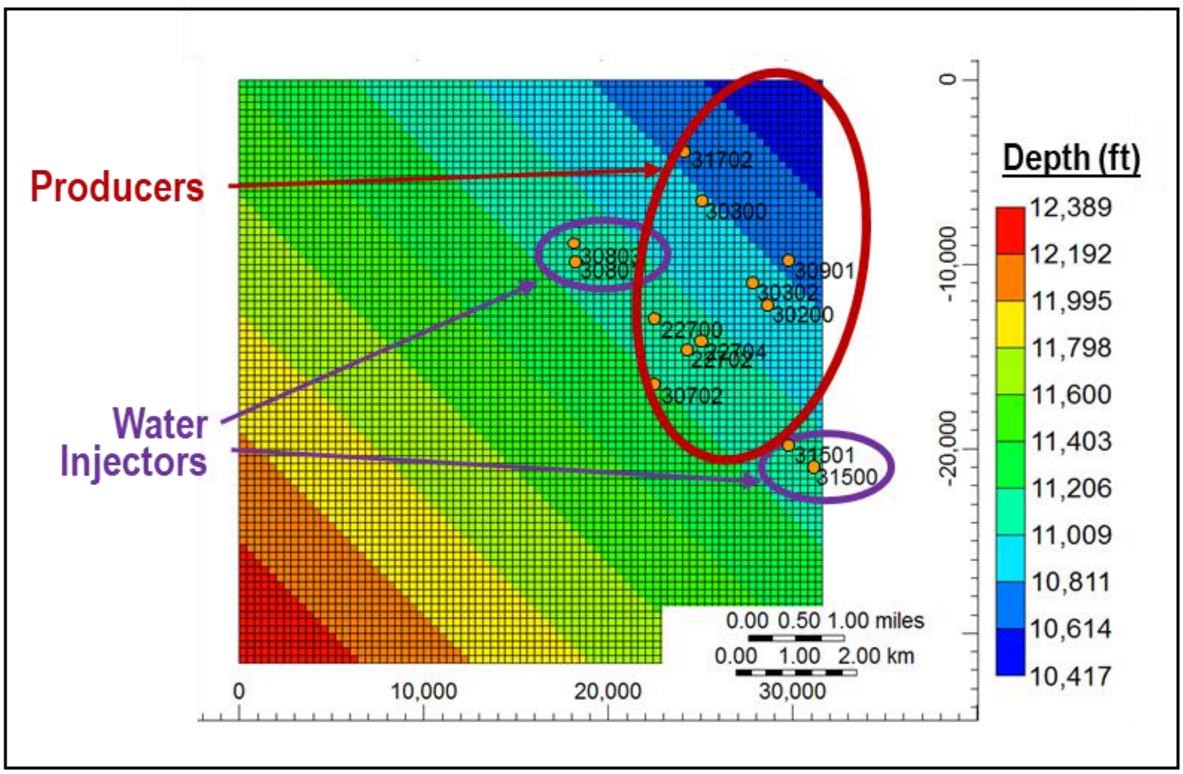
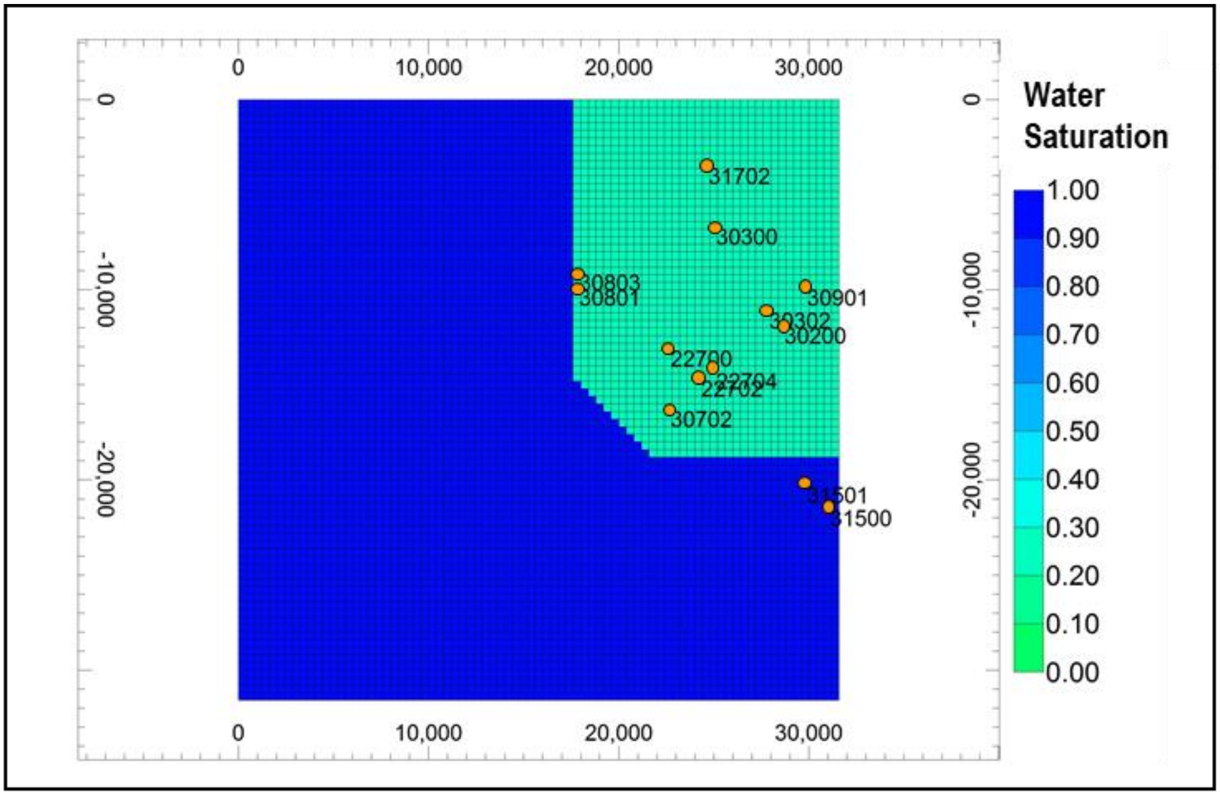


Exhibit 4-2 shows the reservoir model, grid blocks, and initial water saturation for the Petronius oil field Block VK 786 J-2 Sand and its associated aquifer. [7]

Exhibit 4-2. Petronius oil field Block VK 786 J-2 Sand reservoir model and grid blocks



4.2 Calibrating the Reservoir Model

To calibrate the Petronius oil field Block VK 786 J-2 Sand's reservoir properties, a history match was performed of the oil, gas, and water production reported for the J-2 Sand, presented previously in Exhibit 3-3. Reported fluid production values were closely matched using GEM, the J-2 Sand structure, and its reservoir properties and other parameters, as shown in Exhibit 4-3 and Exhibit 4-4. [7]

Exhibit 4-3. History match of cumulative fluid production, Petronius oil field Block VK 786 J-2 Sand

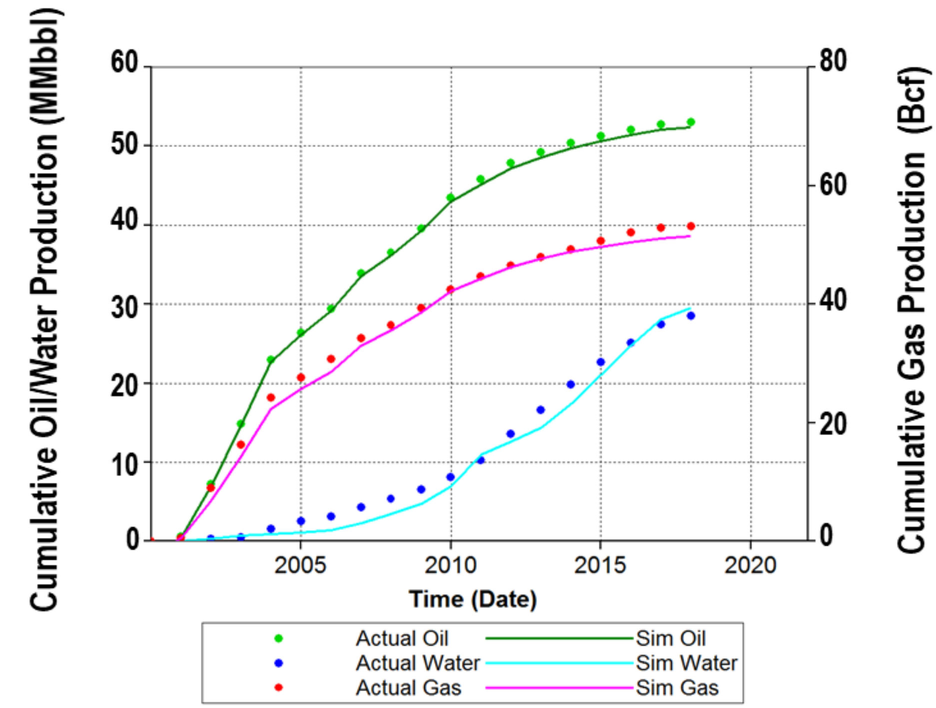
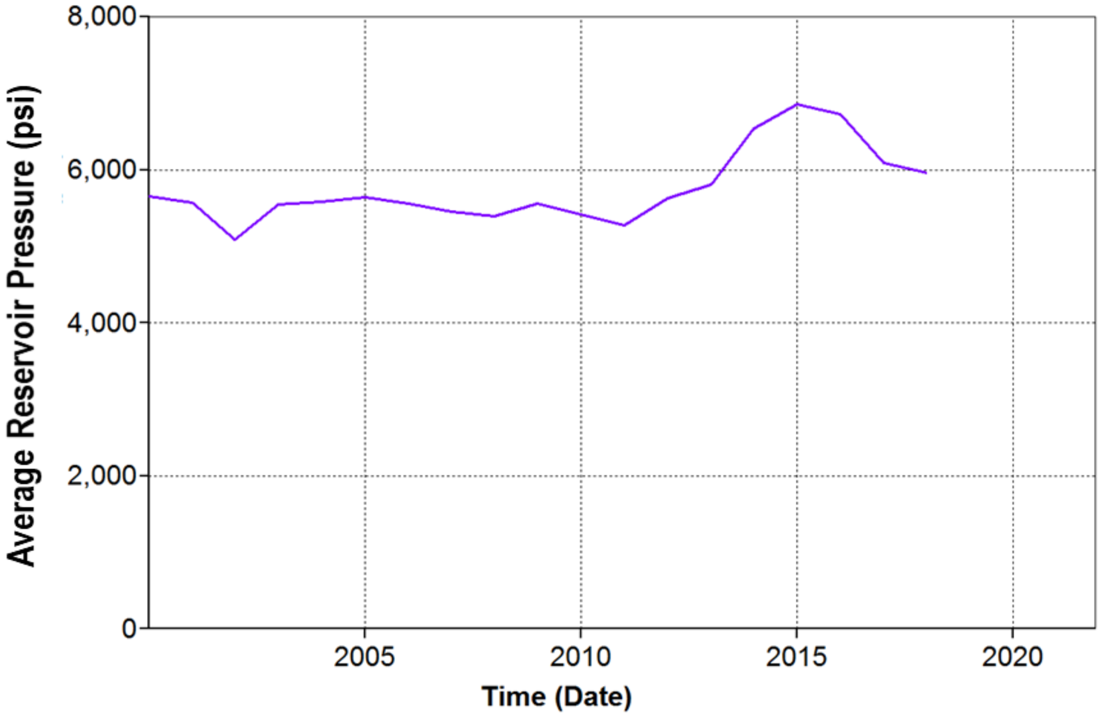


Exhibit 4-4. Comparison of actual and history-matched values for oil, gas, and water production, Petronius oil field Block VK 786 J-2 Sand

Fluid	Actual Data	History Matched Data
Oil (MMbbl)	53	52.4
Gas (Bcf)	53	51.4
Water (MMbbl)	28.5	29.4

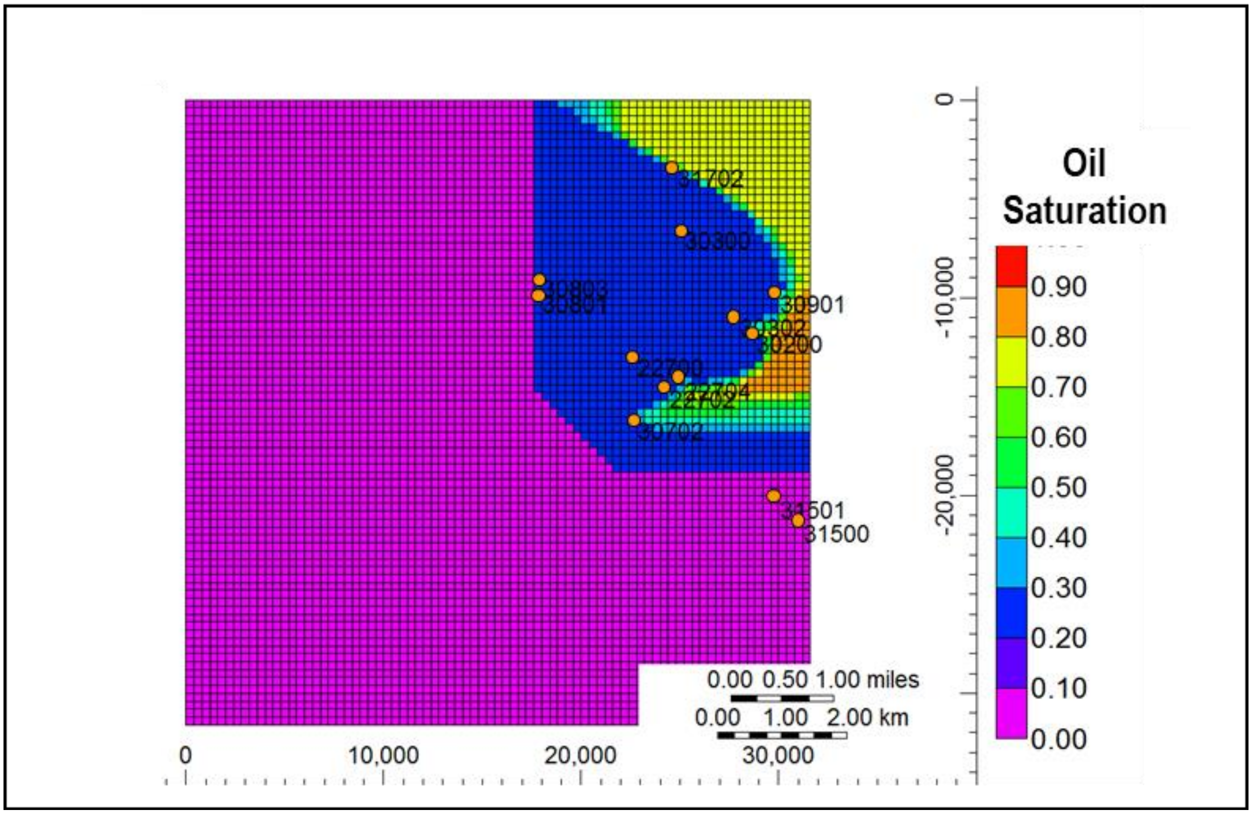
An important output of the history match was the estimate of J-2 Sand reservoir pressure at the end of primary production (Exhibit 4-5). This value is important for designing injection volumes and schedules for the proposed miscible CO_2 flood in the J-2 Sand.

Exhibit 4-5. Reservoir pressure from history match of fluid production, Petronius oil field Block VK 786 J-2 Sand



An equally important output of the history match was establishing the location of the oil remaining in the Petronius oil field Block VK 786 J-2 Sand reservoir at the end of the waterflood (Exhibit 4-6). [7] This information helped establish the optimum location for placing the new CO_2 injection well for modeling the CO_2 flood. The initial oil saturation in the oil zone before primary and waterflood production was estimated at 0.77 with a formation volume factor of 1.44.

Exhibit 4-6. Oil saturation at end of waterflood, Petronius oil field Block VK 786 J-2 Sand



5 GEM Modeling of the Performance of the CO_2 Flood, Petronius Oil Field Block VK 786 J-2 Sand

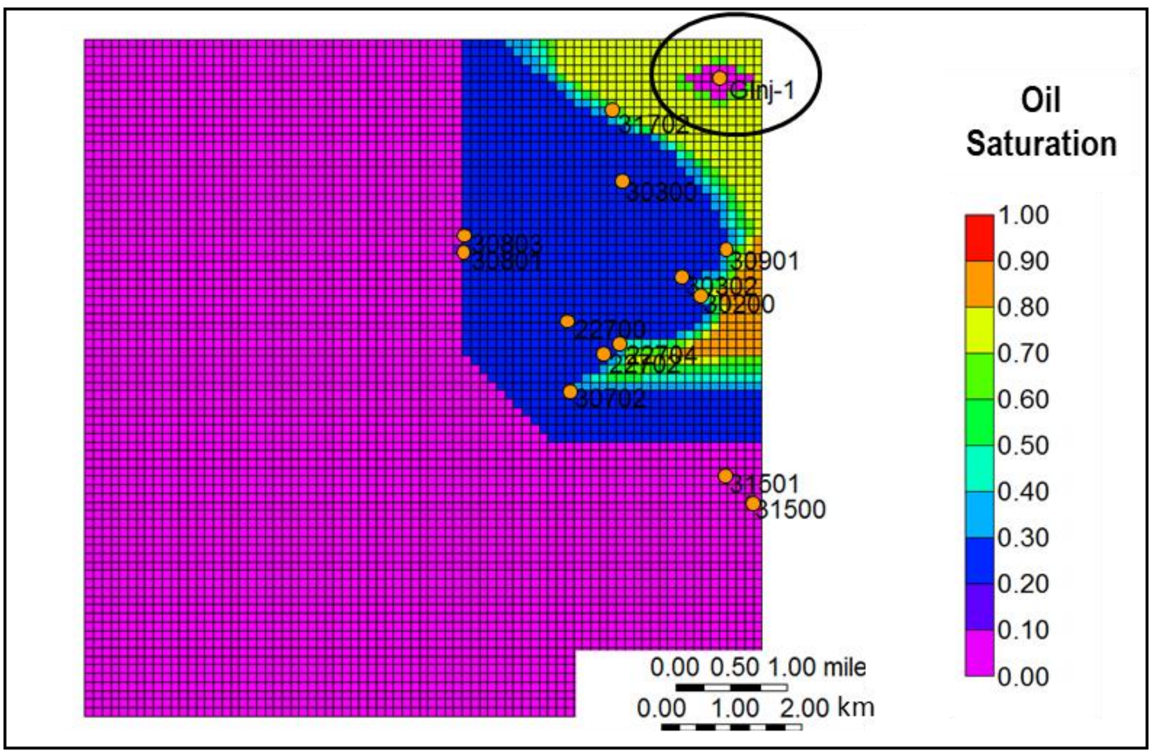
The reservoir model constructed for the Petronius oil field Block VK 786 J-2 Sand (Section 4) was placed into GEM to evaluate the expected performance of the CO_2 flood.

5.1 CO_2 Flood Design

Given the moderate (1.8 degree) structural dip of the formation, its high permeability, the performance of the waterflood, and the location of the remaining oil after primary recovery, the design of the CO_2 flood in the Petronius oil field Block VK 786 J-2 Sand was as follows:

- Drill an updip CO_2 injection well on the crest of formation (Exhibit 5-1)). [7]
- Inject continuous CO_2 at a rate of 25 MMcfd into the J-2 Sand for 40 years
- Shut-in the one previously drilled, still active water injection well
- Operate the CO_2 flood using a bottom hole production back pressure of 4,000 psi
- Shut in one of the active production wells (near the CO_2 injector) and produce fluids from the remaining active five production wells
- Operate the CO_2 flood using a quarter of a five-spot pattern, with three closely spaced, active wells representing one production well and the other two closely spaced, active wells representing the second production well

Exhibit 5-1. Structure and well locations for CO_2 flood, Petronius oil field Block VK 786 J-2 Sand

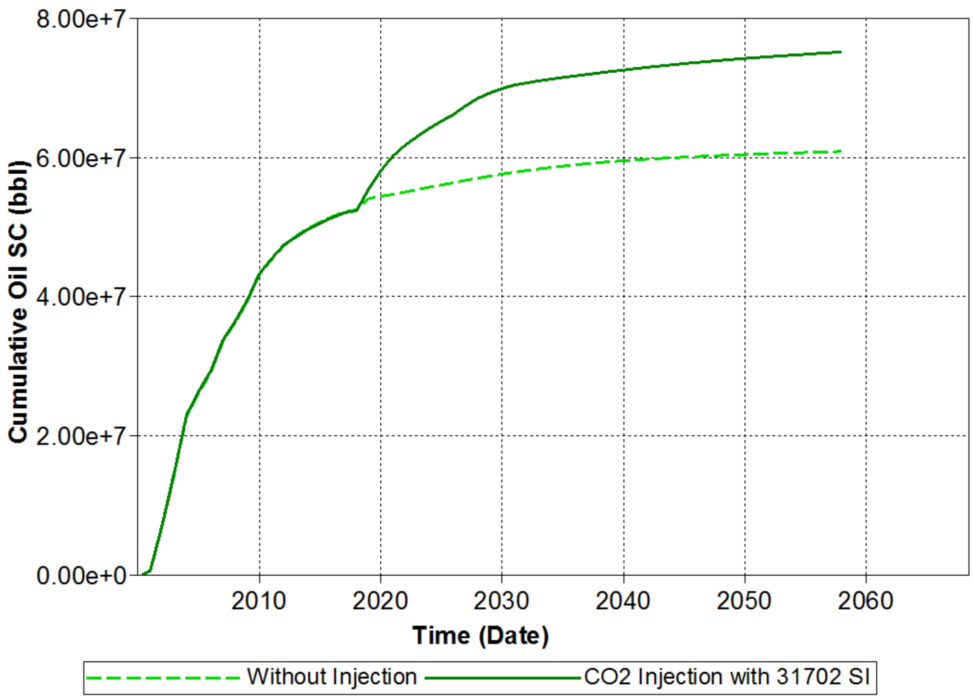


5.2 Calculated Oil Recovery

GEM modeling of the CO_2 flood in the Petronius oil field Block VK 786 J-2 Sand provided the following volumes of incremental oil recovery (beyond primary and waterflood) (Exhibit 5-2). [7]

- 14.3 MMbbl of incremental oil recovery following 40 years of CO_2 injection, equal to 13.5 percent of OOIP

Exhibit 5-2. Cumulative oil recovery, continuation of waterflood incremental from CO_2 Flood, Petronius oil field Block VK 786 J-2 Sand



5.3 Calculated CO_2 Injection, Production, and Storage

GEM modeling of the CO_2 flood in the Petronius oil field Block VK 786 J-2 Sand also provided the following data on CO_2 injection, production, and storage—total gross CO_2 injection of 365 Bcf, including CO_2 production, recycling, and reinjection of 226 Bcf and total CO_2 storage of 139 Bcf for the 40-year CO_2 flood (Exhibit 5-3).

Exhibit 5-3. Cumulative CO_2 injection and production, Petronius oil field Block VK 786 J-2 Sand

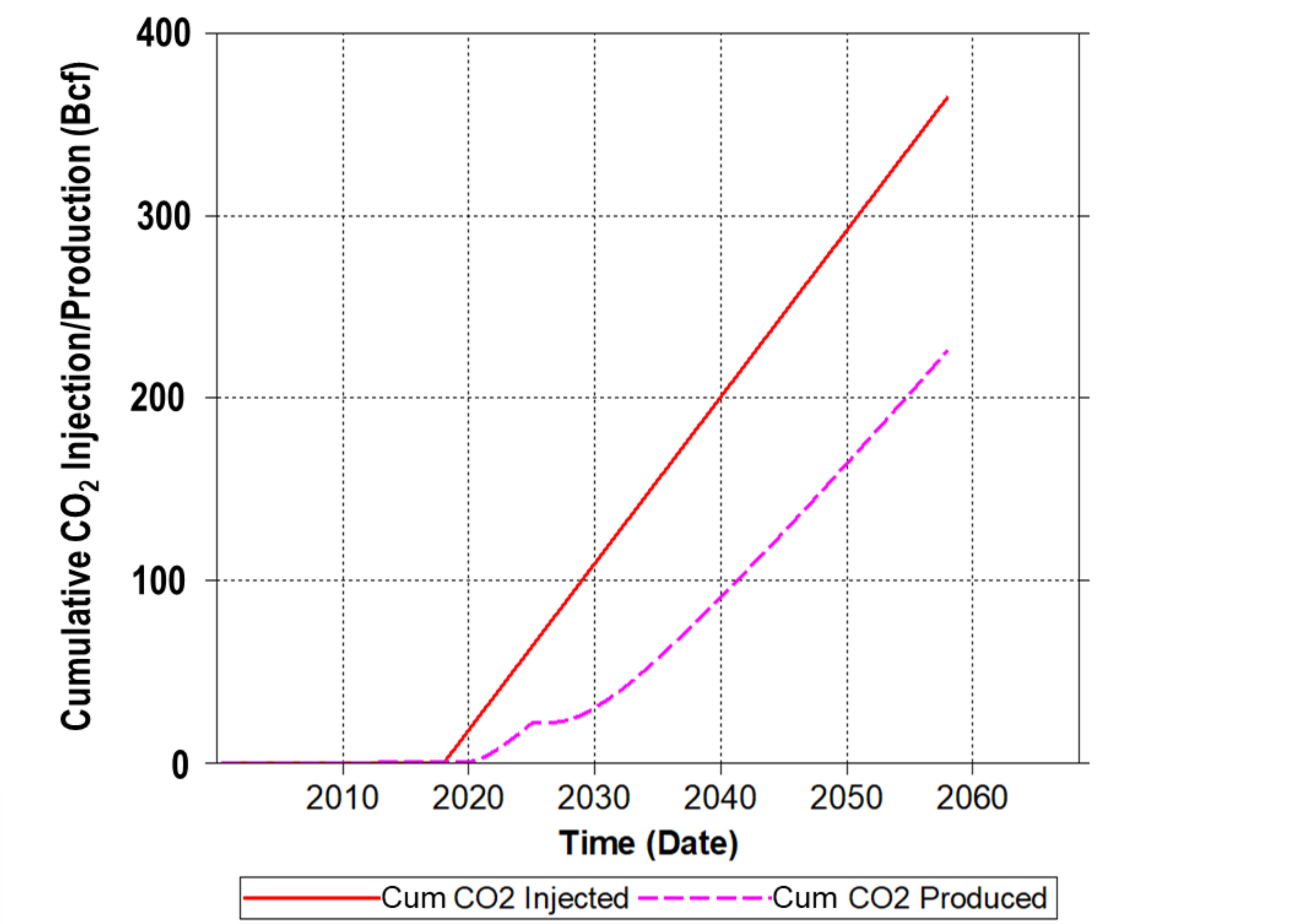


Exhibit 5-4 provides the annual and cumulative data for oil production and the cumulative data for CO_2 injection and production from the Petronius oil field Block VK 786 J-2 Sand. For the 40-year CO_2 flood, the key CO_2 to oil ratios were 25.5 thousand cubic feet per barrel (Mcf/bbl) (gross) and 9.7 Mcf/bbl (net).

Exhibit 5-4. Oil production, CO_2 injection, and CO_2 production; GEM modeling of the CO_2 flood, Petronius oil field Block VK 786 J-2 Sand

Year	Incremental Oil Production		Cumulative CO_2	
	Annual (bbl/d)	Cumulative (MMbbl)	Injection (Bcf)	Production (Bcf)
2019	3,740	1.4	9.1	0.3
2020	6,310	3.7	18.3	0.5
2021	5,030	5.5	27.4	2.5
2022	3,340	6.7	36.5	6.4
2023	2,480	7.6	45.7	11.0
2024	2,290	8.5	54.8	16.2
2025	1,890	9.2	63.9	21.9
2030	1,000	12.3	109.6	30.3
2035	140	12.8	155.2	57.4
2040	210	13.0	200.9	90.9
2045	230	13.5	246.6	126.9
2050	170	13.8	292.2	164.3
2055	150	14.1	337.9	202.7
2058	140	14.3	365.2	226.3

6 Modeling the Performance of the Petronius Oil Field, Block VK 786 J-2 Sand CO_2 Flood with CO_2 Prophet Model

In parallel with GEM, the CO_2 Prophet Model was used to evaluate the expected performance of the CO_2 flood in the Petronius oil field Block VK 786 J-2 Sand using the volumetric and reservoir properties and data provided in Section 3. Exhibit 6-1 lists the key volumetric and reservoir properties data for the Petronius oil field Block VK 786 J-2 Sand, and Exhibit 6-2 and Exhibit 6-3 are the input data sheets for modeling the CO_2 flood in the Petronius oil field Block VK 786 J-2 Sand using the CO_2 Prophet Model.

To capture the heterogeneity of the J-2 Sand, a Dykstra-Parsons (DP) coefficient of 0.75 (the minimum value used in CO_2 Prophet modeling) was used. The impact of using a more favorable DP coefficient of 0.5 that would represent a highly uniform reservoir sand was also examined.[a]

[a] The DP coefficient is used by the reservoir engineering community to define the heterogeneity of a reservoir, with a low value (0.5 or so) reflecting low heterogeneity and a high value (0.9 or so) reflecting high heterogeneity. A full-scale, compositional reservoir model typically assigns different permeability values to discrete units of net pay (the vertical stack of grid blocks) to capture the reservoir heterogeneity.

Exhibit 6-1. Volumetric and reservoir properties, Petronius oil field Block VK 786 J-2 Sand

Basin Name	**Deep Water**	**Area:**	**Offshore**
State	**LA**		To change Basin, click on cell above
Field Name	**VK786 (Petronius)**	**Reservoir No.**	**24485**
		Manual	**24485**
Reservoir	**VK786MID_TEX_W**	**Total Reservoirs**	**24188**

Reservoir Parameters:		**Oil Production**		**Volumes**	
Area (A)	**5,700**	Producing Wells (active)	**6**	OOIP (MMbl)	**106.0**
Net Pay (ft)	**16**	Producing Wells (shut-in)	**3**	Cum P/S Oil (MMbl)	**52.0**
Depth (ft)	**10,563**	2016 Production (MMbbl)	**0.00**	EOY 2016 P/S Reserves (MMbl)	**1.3**
Lithology	**1**	2016 P/S Production (MMbbl)	**0.00**	Ultimate P/S Recovery (MMbl)	**53.3**
Dip (°)	**0**	Cum Oil Production (MMbbl)	**52.0**	Remaining (MMbbl)	**52.7**
Gas/Oil Ratio (Mcf/Bbl)	**982**	EOY 2014 Oil Reserves (MMbbl)	**1.3**	Ultimate P/S Recovered (%)	**50%**
Salinity (ppm)	**100,000**	Water Cut	**0.0%**	P/S Sweep Efficiency (%)	**99%**
Gas specific Gravity	**0.65**			**OOIP Volume Check**	
Historical Well Spacing (Acres)	**-**	**Water Production**		Reservoir Volume (AF)	**91,227**
Current Pattern Acreage (Acres)	**-**	2014 Water Production (Mbbl)	**0.00**	Bbl/AF	**1,162**
Permeability (mD)	**398**	Daily Water (Mbbl/d)	**0.00**	OOIP Check (MMbl)	**106.0**
Porosity (%)	**28%**				
Reservoir Temp (deg F)	**182**	**Injection**		**SROIP Volume Check**	
Initial Pressure (psi)	**5,800**	Injection Wells (active)	**1**	Reservoir Volume (AF)	**91,227**
Pressure (psi)	**-1**	Injection Wells (shut-in)	**3**	Swept Zone Bbl/AF	**569**
		2008 Water Injection (MMbbl)	**0.00**	SROIP Check (MMbbl)	**51.9**
B_{oi}	**1.44**	Daily Injection - Field (Mbbl/d)	**0.00**		
B_o @ S_o, swept	**1.44**	Cum Injection (MMbbl)	**0.00**		
S_{oi}	**0.77**	Daily Inj per Well (Bbl/d)	**0.00**	**ROIP Volume Check**	
S_{or}	**0.38**			ROIP Check (MMbl)	**52.7**
S_{wi}	**0.23**	**EOR**			
S_w	**0.62**	Type	**0**		
		2014 EOR Production (MMbbl)	**0.00**		
API Gravity	**31.2**	Cum EOR Production (MMbbl)	**0.00**		
Viscosity (cp)	**0.90**	EOR 2014 Reserves (MMbbl)	**0.00**		
		Ultimate Recoverery (MMbbl)	**0.00**		
Dykstra-Parsons	**0.75**	**OGJ Data**			
Miscibility:		2014 Enhanced Production (B/d)	**0.00**		
C5+ Oil Composition	212.8	2014 Total Production (B/d)	**0.00**		
Min Required Miscibility Press(psig)	2609.9	Project Acreage	**0**		
Depth > 3000 feet	1	Scope	**0**		
API Gravity >= 17.5	1	# Projects	**0**		
Pr > MMP	0				
Flood Type	Miscible				

Exhibit 6-2. Input data sheet, CO_2 Prophet modeling of Petronius oil field Block VK 786 J-2 Sand (DP = 0.75)

```
'Petronius 5670 AC Area - Five Spot - DP 75 - SO 37.7'
'********** 'WELL AND PATTERN DATA ********'
'PATTERN'
'5S'
'NWELLS       NOINJ'
2,             1
'WELLS        WELLY         WELLQ'
0,            0,             1
1,            1,            -1
'NBNDPT'
 5
'BOUNDX       BOUNDY'
0,             0
0,             1
1,             1
1,             0
0,             0
'*************  PROGRAM CONTROLS  ********'
'LWGEN        OUTTIM'
'N',           1
'**** RELATIVE PERMEABILITY PARAMETERS ***'
'SORW         SORG          SORM'
0.25,          0.3,           0.1
'SGR          SSR'
0.3,          0.3
'SWC          SWIR'
0.3,           0.3
'KROCW        KWRO          KRSMAX        KRGCW'
0.8,          0.2,          0.4,           0.45
'EXPOW        EXPW          EXPS          EXPG          EXPOG'
2,            2,            2,            2,            2
'KRMSEL       W'
1,             0.999
'***************  FLUID DATA  ************'
'VISO         VISW'         CO2SOL 0 REDFAC 0.10 CO2INJ
0.9,         0.43
'BO           RS            API           SALN          GSG'
1.44,         982,         31.2,         100000,       0.65 |
'************** RESERVOIR DATA ***********'
'TRES         P             MMP'
182,          5800,        2610
'DPCOEF       PERMAV        THICK         POROS         NLAYERS'
0.75,         398,          16,            0.28,         10
'SOINIT       SGINIT        SWINIT'
0.377,          0,          0.623
'AREA         XKVH'
993168000,      0.5
'********** INJECTION PARAMETERS *********'
'NTIMES       WAGTAG'
1,             'T'
'HCPVI        WTRRAT        SOLRAT        TMORVL'
1.10,         45452,         100,           0.0
```

Exhibit 6-3. Input data sheet, CO_2 Prophet modeling of Petronius oil field Block VK 786 J-2 Sand (DP = 0.5)

```
'Petronius 5670 AC Area - Five Spot - DP 50 - SO 37.7'
'********** 'WELL AND PATTERN DATA ********'
'PATTERN'
'5S'
'NWELLS       NOINJ'
2,             1
'WELLS        WELLY         WELLQ'
0,            0,             1
1,            1,            -1
'NBNDPT'
 5
'BOUNDX       BOUNDY'
0,             0
0,             1
1,             1
1,             0
0,             0
'*************  PROGRAM CONTROLS  ********'
'LWGEN        OUTTIM'
'N',           1
'**** RELATIVE PERMEABILITY PARAMETERS ***'
'SORW         SORG          SORM'
0.25,          0.3,           0.1
'SGR          SSR'
0.3,          0.3
'SWC          SWIR'
0.3,           0.3
'KROCW        KWRO          KRSMAX        KRGCW'
0.8,          0.2,          0.4,           0.45
'EXPOW        EXPW          EXPS          EXPG          EXPOG'
2,            2,            2,            2,            2
'KRMSEL       W'
1,             0.999
'***************  FLUID DATA  ************'
'VISO         VISW'         CO2SOL 0 REDFAC 0.10 CO2INJ
0.9,         0.43
'BO           RS            API           SALN          GSG'
1.44,         982,         31.2,         100000,       0.65
'************** RESERVOIR DATA ***********'
'TRES         P             MMP'
182,          5800,        2610
'DPCOEF       PERMAV        THICK         POROS         NLAYERS'
0.50,         398,          16,            0.28,         10
'SOINIT       SGINIT        SWINIT'
0.377,          0,          0.623
'AREA         XKVH'
993168000,      0.5
'********** INJECTION PARAMETERS *********'
'NTIMES       WAGTAG'
1,            'T'
'HCPVI        WTRRAT        SOLRAT        TMORVL'
1.10,         45452,         100,           0.0
```

6.1 CO_2 FLOOD DESIGN

The structural setting and well locations of the Petronius oil field Block VK 786 J-2 Sand were modeled with the CO_2 Prophet Model using the following features.

- Drill a new CO_2 producer at the crest of the formation and operate the CO_2 flood as a quarter of a 5-spot pattern
- Inject continuous CO_2 at a rate of 25 MMcfd for 40 years, reaching a cumulative injection of CO_2 of 365 Bcf, equal to the CO_2 injected in GEM (hydrocarbon pore volume of 1.0)

6.2 CALCULATED OIL RECOVERY

CO_2 Prophet modeling of the CO_2 flood in the Petronius oil field Block VK 786 J-2 Sand with a DP coefficient of 0.75 provided incremental oil recovery (beyond the waterflood) of 10.8 MMbbl. CO_2 Prophet modeling of the CO_2 flood in the J-2 Sand with a DP coefficient of 0.5 provided incremental oil recovery (beyond the waterflood) of 17.4 MMbbl.

6.3 CALCULATED CO_2 INJECTION, PRODUCTION, AND STORAGE

CO_2 Prophet modeling of the CO_2 flood in the Petronius oil field Block VK 786 J-2 Sand provided the following data for CO_2 injection, CO_2 production, and CO_2 storage for a 40-year CO_2 flood.

- For the DP = 0.75 case, CO_2 injection of 365 Bcf, CO_2 production of 238 Bcf, and CO_2 storage of 127 Bcf for a 40-year CO_2 flood, with CO_2 to oil ratios of 33.8 Mcf/bbl (gross) and 11.7 Mcf/bbl (net)
- For the DP = 0.5 case, CO_2 injection of 365 Bcf, CO_2 production of 190 Bcf, and CO_2 storage of 175 Bcf for a 40-year CO_2 flood, with CO_2 to oil ratios 21.0 Mcf/bbl (gross) and 10.1 Mcf/bbl (net)

Exhibit 6-4 (for DP = 0.75) and Exhibit 6-5 (for DP = 0.5) provide the data for oil production, CO_2 injection, and CO_2 production of the performance of the CO_2 flood in the Petronius oil field Block VK 786 J-2 Sand using the CO_2 Prophet Model.

Exhibit 6-4. Cumulative oil production, CO_2 injection, and CO_2 production; CO_2 Prophet modeling of the CO_2 flood, Petronius oil field Block VK 786 J-2 Sand (DP = 0.75)

Year	CO_2 Inj (Bcf)	Oil Prod (MMbbl)	CO_2 Prod (Bcf)	Purch CO_2 (Bcf)	CO_2 Util (Mcf/bbl)
1	9.1	0.5	-	9.1	16.7
2	18.3	1.1	-	18.3	16.6
3	27.4	2.0	0.1	27.3	13.7
4	36.5	2.8	2.5	34.1	12.1
5	45.7	3.3	6.6	39.0	11.7
6	54.8	3.7	11.6	43.2	11.6
7	63.9	4.1	16.8	47.1	11.5
8	73.1	4.5	22.0	51.0	11.3
9	82.2	4.8	27.9	54.3	11.3
10	91.3	5.1	33.9	57.5	11.3
11	100.4	5.4	39.6	60.8	11.2
12	109.6	5.8	45.1	64.4	11.0
13	118.7	6.3	50.8	67.9	10.8
14	127.8	6.6	57.0	70.8	10.8
15	137.0	6.8	63.5	73.4	10.8
16	146.1	7.0	70.2	75.9	10.9
17	155.2	7.1	77.0	78.3	11.0
18	164.4	7.3	83.8	80.5	11.0
19	173.5	7.5	90.6	82.9	11.1
20	182.6	7.7	97.4	85.2	11.1
21	191.8	7.9	104.2	87.6	11.2
22	200.9	8.0	111.1	89.8	11.2
23	210.0	8.2	118.0	92.0	11.3
24	219.2	8.3	125.0	94.1	11.3
25	228.3	8.5	132.0	96.3	11.4
26	237.4	8.7	138.8	98.6	11.4
27	246.5	8.9	145.7	100.9	11.4
28	255.7	9.1	152.5	103.2	11.4
29	264.8	9.3	159.4	105.4	11.4
30	273.9	9.5	166.3	107.6	11.4
31	283.1	9.6	173.3	109.7	11.4
32	292.2	9.8	180.4	111.8	11.4
33	301.3	10.0	187.6	113.8	11.4
34	310.5	10.1	194.8	115.7	11.5
35	319.6	10.2	202.0	117.6	11.5
36	328.7	10.3	209.3	119.4	11.5
37	337.9	10.5	216.6	121.3	11.6
38	347.0	10.6	223.9	123.1	11.6
39	356.1	10.7	231.2	125.0	11.7
40	365.3	10.8	238.4	126.8	11.7

Exhibit 6-5. Cumulative oil production, CO_2 injection, and CO_2 production; CO_2 Prophet modeling of the CO_2 flood, Petronius oil field Block VK 786 J-2 Sand (DP = 0.5)

Year	CO_2 Inj (Bcf)	Oil Prod (MMbbl)	CO_2 Prod (Bcf)	Purch CO_2 (Bcf)	CO_2 Util (Mcf/bbl)
1	9.1	0.5	-	9.1	16.7
2	18.3	1.1	-	18.3	16.7
3	27.4	1.6	-	27.4	16.7
4	36.5	2.3	-	36.5	16.2
5	45.7	3.1	0.0	45.6	14.8
6	54.8	3.9	1.3	53.5	13.7
7	63.9	4.6	4.0	60.0	13.2
8	73.1	5.2	7.0	66.0	12.7
9	82.2	5.8	10.4	71.7	12.4
10	91.3	6.4	14.3	77.1	12.1
11	100.4	6.9	18.3	82.2	11.8
12	109.6	7.5	22.4	87.2	11.5
13	118.7	8.1	27.1	91.6	11.4
14	127.8	8.5	32.0	95.8	11.3
15	137.0	9.0	37.0	99.9	11.1
16	146.1	9.4	42.1	104.0	11.0
17	155.2	9.9	47.3	107.9	10.9
18	164.4	10.3	52.6	111.8	10.8
19	173.5	10.8	58.0	115.5	10.7
20	182.6	11.2	63.4	119.2	10.6
21	191.8	11.7	69.0	122.8	10.5
22	200.9	12.1	74.7	126.1	10.5
23	210.0	12.4	80.6	129.4	10.4
24	219.2	12.8	86.6	132.6	10.4
25	228.3	13.1	92.5	135.7	10.3
26	237.4	13.5	98.6	138.8	10.3
27	246.5	13.8	104.8	141.7	10.3
28	255.7	14.1	111.2	144.5	10.2
29	264.8	14.4	117.7	147.1	10.2
30	273.9	14.6	124.2	149.7	10.2
31	283.1	14.9	130.8	152.2	10.2
32	292.2	15.1	137.4	154.8	10.2
33	301.3	15.4	143.9	157.4	10.2
34	310.5	15.7	150.4	160.0	10.2
35	319.6	16.0	156.9	162.7	10.2
36	328.7	16.3	163.3	165.4	10.2
37	337.9	16.6	169.8	168.1	10.1
38	347.0	16.9	176.3	170.7	10.1
39	356.1	17.1	182.9	173.2	10.1
40	365.3	17.4	189.6	175.7	10.1

7 Comparative Analysis of GEM and CO_2 PROPHET Modeling of CO_2 Flood, Petronius Oil Field Block VK 786 J-2 Sand

Based on the information provided in Section 5 and Section 6, it was found that the CO_2 Prophet Model was able to reasonably represent the performance of the CO_2 flood modeled using the more sophisticated GEM. Exhibit 7-1 provides a comparison of the results for the Petronius oil field Block VK 786 J-2 Sand from the two reservoir models. The DP reservoir heterogeneity values of 0.5 to 0.75 used in the CO_2 Prophet Model provide results that bracket the performance of the CO_2 flood calculated using GEM.

Exhibit 7-1. Comparative assessments of performance for the Petronius oil field Block VK 786 J-2 Sand

Parameter	CO_2 Flood Performance GEM	CO_2 Flood Performance CO_2 Prophet Model	
		DP = 0.75	DP = 0.5
OOIP (MMbbl)	106	106	106
CO_2 Injection (Bcf)	365	365	365
CO_2 Production (Bcf)	226	238	190
CO_2 Storage (Bcf)	139	127	175
Cumulative Oil Recovery			
MMbbl	14.3	10.8	17.4
% of OOIP	13.6	10.2	16.4
CO_2/Oil Ratio (Mcf/bbl)			
Gross	25.5	33.8	21.0
Net	9.7	11.8	10.1

8 REFERENCES

[1] National Energy Technology Laboratory, "StrmtbFlow Fortran Program," U.S. Department of Energy, 31 October 2019. [Online]. Available: https://netl.doe.gov/energy-analysis/details?id=3940. [Accessed 14 May 2020].

[2] National Energy Technology Laboratory, "StrmtbGen Fortran Program," U.S. Department of Energy, 31 October 2019. [Online]. Available: https://netl.doe.gov/energy-analysis/details?id=3939. [Accessed 14 May 2020].

[3] Kuuskraa, V., Oudinot, A., and Wallace, M., "Cognac Offshore Oil Field Case Study," U.S. Department of Energy, National Energy Technology Laboratory, Pittsburgh, PA, 2019.

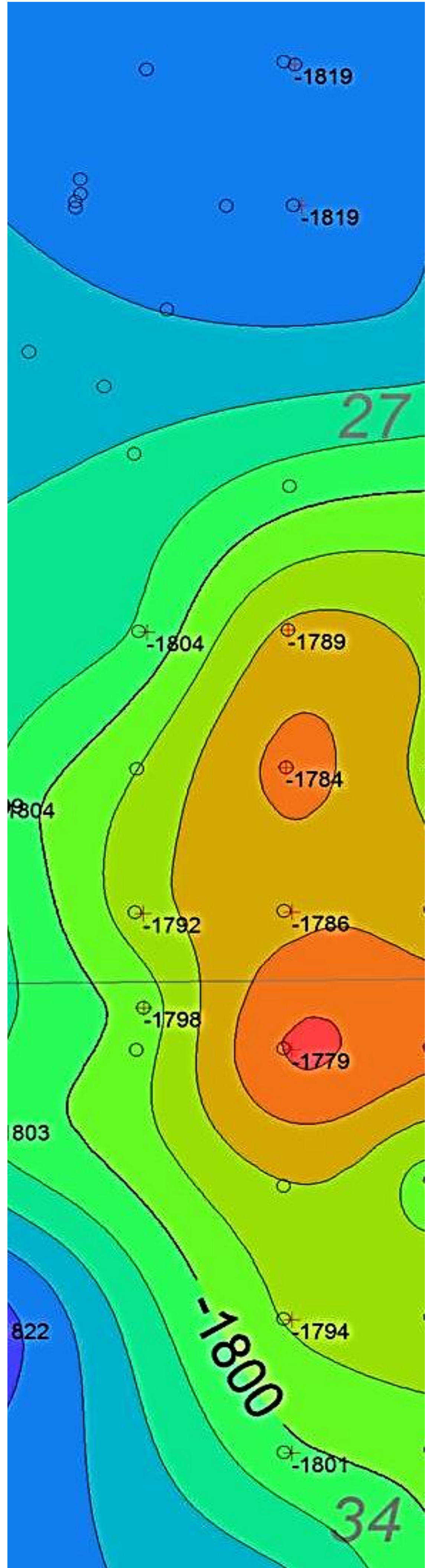
[4] Bureau of Ocean Energy Management, "Outer Continental Shelf, Estimated Oil and Gas Reserves, Gulf of Mexico OCS Region," U.S. Department of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region, OCS BOEM 2020-028, 2018.

[5] Duan, S., Lach, J. R., Beadall, K. K., and Li, X., "Water Injection in Deepwater, Over-Pressured Turbidites in the Gulf of Mexico: Past, Present, and Future," in *Offshore Technology Conference, doi:10.4043/24111-MS*, May 6, 2013.

[6] Advanced Resources International, "Internal Use Product," Washington, D.C., 2018.

[7] DrillingInfo/Enverus, "Enverus DrillingInfo Desktop," [Online]. Available: https://www.enverus.com/. [Accessed 2019].

[8] Li, L., Sheng, J. J., and Xu, J., "Gas Selection for Huff-n-Puff EOR in Shale Oil Reservoirs Based upon Experimental and Numerical Study," Society of Petroleum Engineers, doi:10.2118/185066-MS, 2017.



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